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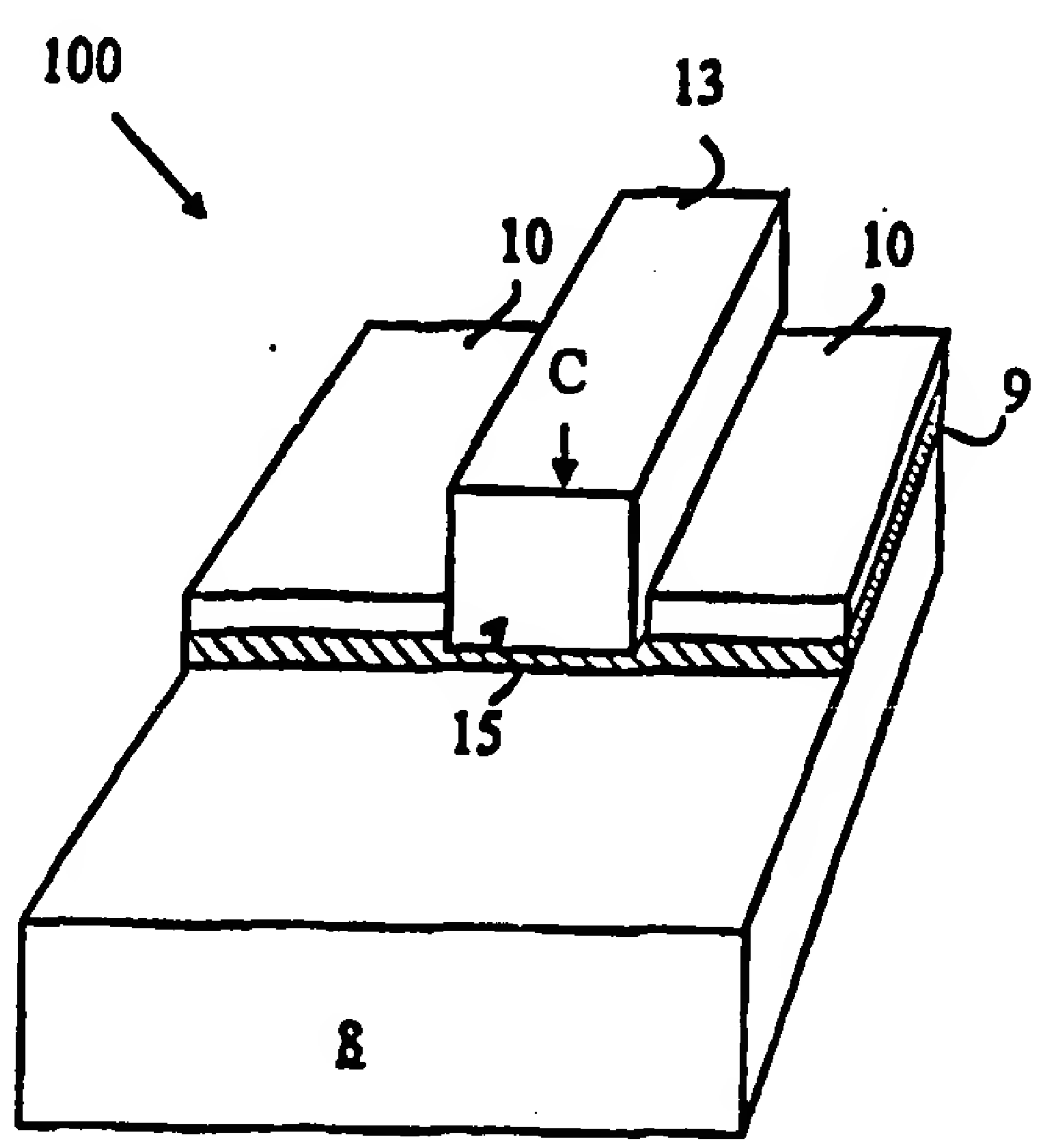
(54) Title: SEMICONDUCTOR LASER DEVICE

(57) Abstract

A method for fabricating a semiconductor laser diode and the laser diode constructed therewith. A laser diode according to the present invention is constructed by depositing a buffer layer (9) on a substrate (8). A crystalline layer (10-13) is then deposited on the buffer layer (9). The crystalline layer (10-13) includes the waveguide for the laser. A portion (110) of the buffer layer (9) is etched from under the crystalline layer (10-13) leaving a portion (110) of the crystalline layer (10-13) cantilevered over the substrate (8). The crystalline layer (10-13) is then cleaved in the cantilevered portion (110) to generate a reflecting surface (15) for reflecting light generated in the waveguide. This method is well suited for GaN based laser diodes that are to be constructed on sapphire substrates.



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Semiconductor Laser Device

Field of the Invention

The present invention relates to semiconductor laser diodes and more particularly relates to semiconductor laser diodes having cleaved facets.

Background of the Invention

Recently, the development of semiconductor light-emitting elements has advanced to the point that such elements are being applied to a variety of fields. The development of semiconductor light-emitting elements began with the development of red and yellow light-emitting elements and was later followed by the development of blue semiconductor light-emitting elements. Semiconductor light-emitting elements are divided into light-emitting diodes (LEDs) and laser diodes (LDs). To provide full color images in a display, elements that emit all of the three primary colors are required. Hence, the development of blue semiconductor LEDs has greatly expanded the uses for these elements.

Blue LDs have the potential for increasing the storage capacity of optical disks over the densities currently available in compact disk systems based on red laser diodes. Increased storage capacity will open new markets for compact disks in motion picture distribution.

One class of blue emitting elements is based on group III-V nitride films such as GaN epilayers grown on sapphire substrates. To fabricate a laser, an appropriate optical cavity having parallel mirrors at each end of the cavity must be formed. The laser cavity is typically formed by sandwiching an active gain layer between two layers of GaN doped to form n-type and p-type semiconductors. The GaN layers are constructed so as to form a waveguide. The ends of the waveguide are mirrors that reflect the light generated in the active region back and forth. In GaN based LDs the mirrors are typically formed by etching the ends of the waveguide to provide the

reflecting surface of the mirror.

It should be noted that the techniques based on cleaving the layers, which are utilized in the analogous devices, based on zinc blende III-V compounds do not work with GaN. The GaN layers are typically deposited on sapphire substrates that are difficult to cleave. Even if broken by force, the sapphire, GaN buffer layer deposited on the sapphire, and the GaN forming the active layer are unified at the crystal level. Hence, it is difficult to control the cleaving operation to assure that the facets are provided in the desired planes relative to the active layer. To overcome the problems associated with cleaving, etching techniques have been employed.

Unfortunately, the surfaces formed by the etching operation do not form perfect mirror planes. Minute irregularities develop on these surfaces which scatter the light generated in the active layer. This scattering lowers the efficiency of the device, and hence, increases the current that must be applied to achieve lazing. The additional current increases the heat generated in the device and leads to decreased reliability.

Broadly, it is the object of the present invention to provide an improved GaN based semiconductor laser and method for making the same.

It is a further object of the present invention to provide an improved method for cleaving the GaN layers to provide the end mirrors of the laser cavity.

These and other objects of the present invention will become apparent to those skilled in the art from the following detailed description of the invention and the accompanying drawings.

Summary of the Invention

The present invention is a method for fabricating a semiconductor laser diode and the laser diode constructed therewith. A laser diode according to the present

invention is constructed by depositing a buffer layer on a substrate. A crystalline layer is then deposited on the buffer layer. The crystalline layer includes the waveguide for the laser. A portion of the buffer layer is etched from under the crystalline layer leaving a portion of the crystalline layer cantilevered over the substrate. The crystalline layer is then cleaved in the cantilevered portion to generate a reflecting surface for reflecting light generated in the waveguide. This method is well suited for GaN based laser diodes that are to be constructed on sapphire substrates.

Brief Description of the Drawings

Figure 1 is a cross-sectional view of a laser diode.

Figure 2 is a cross-sectional view of a laser diode illustrating the manner in which the end mirrors are normally fabricated.

Figures 3 and 4 are cross-sectional views of the layers deposited in the first stages of the fabrication of a laser diode.

Figures 5-8 are prospective views of a wafer at various stages in the fabrication of a laser diode according to the present invention.

Figures 9-12 are prospective views of a wafer at various stages in the fabrication of a second embodiment of a layer diode according to the present invention.

Detailed Description of the Invention

The present invention may be more easily understood with reference to Figure 1, which is a cross-sectional view of a LD. Light is generated in the active region 7 by the recombination of holes and electrons which are introduced into the region by applying a voltage between contacts 5 and 6 which in turn creates a potential across a

p-n diode formed by GaN layer 3 and 4. The reflecting planes 1 on the boundary of the active region form a waveguide that traps the light generated in the active region. The light is reflected back and forth through the active region by the reflecting planes shown at 2. With each pass, the light is amplified. One of the reflecting planes 2 has a reflectivity that is less than 100%. Light exits the laser through this plane as shown by the arrow in the figure.

As noted above, to obtain a highly efficient laser diode, the reflecting planes shown at 2 must be as close to perfectly parallel mirrors as possible. In general, the layered structure is grown epitaxially on a substrate 8 as shown in Figure 2. If the substrate is relatively soft, the reflecting surfaces for the ends of the waveguide can be generated by cleaving the substrate and attached layers in the direction of the arrows shown at B. Typically, a scribe is used to insert cuts in the back of the substrate, and then, the substrate is broken.

Blue semiconductor lasers are usually fabricated on a sapphire substrate because the lattice constants of sapphire provide the closest match to lattice spacing of GaN. A series of GaN layers are deposited on the sapphire substrate to form the various layers that make up the laser. Unfortunately, the sapphire substrate is too hard to easily break after forming the active layer.

The present invention overcomes this difficulty by utilizing a buffer layer between the sapphire substrate and the GaN layers. The buffer layer material must have two properties. First, it must provide a suitable base material for depositing the GaN layers. Second, the buffer material must allow a selective etch so that a portion of the buffer layer can be removed from under GaN layers to provide a cantilevered structure that can be cleaved by conventional techniques. The preferred buffer layer material is aluminum nitride (AlN).

Refer now to Figure 3 which is a cross-sectional view of the layers deposited on a sapphire substrate 8 as the first step in fabricating a LD 100 according to the present invention. An AlN layer 9 having a thickness from 50 nm to 200 nm is

deposited by metal-organic chemical vapor deposition (MOCVD) at a relatively low temperature of around 500°C. AlN is preferred as the buffer material because a flat film consisting of a GaN single crystal is easily formed on an AlN layer. In addition, etching methods for selectively etching AlN without significantly removing GaN are well known in the art.

After depositing the AlN buffer layer 9, a layer 10 of n-type GaN is deposited. The light-emitting part of the layer composed of GaN based cladding layers 11 and a GaN based active layer 12, and a p-type GaN layer 13 are deposited on AlN layer 9. Referring to Figure 4, the layers are then etched to expose the n-type contact as shown at 101. The exposed area is used to make a connection that becomes the negative terminal of the LD. The positive terminal is deposited on p-type layer 13.

Refer now to Figure 5, which is a perspective view of a portion of wafer on which a plurality of LDs is formed by the method of the present invention. The layered substrate is etched to provide access to the n-type layer as described above. The layered structure is then etched back to the substrate 8 using reactive ion etching to provide regions in which the waveguide protrudes. A typical protruding region is shown at 110. The AlN buffer layer 9 discussed above is shown crosshatched in the figure.

After the reactive ion etching, the portion of the AlN layer under the protrusion 110 is then removed by selectively etching away the exposed AlN layer. This leaves the portion of the waveguide that was included in the protrusion cantilevered over the substrate as shown in Figure 6 at 14. Without the support of the underlying substrate, the GaN layers in the cantilevered region are easily cleaved. The layers may be cleaved by applying ultrasonic vibration or by striking the cantilevered region with a blade at the desired location in the direction indicated by the arrows labeled "C" in Figure 7. The resulting cleaved facets act as the mirrors at the ends of the cavity. A typical facet is shown at 15 in Figure 8, which is a perspective view of one of the LDs after the wafer has been diced to separate the individual LDs.

The reactive ion etch utilized to form the protrusions discussed above may be eliminated if the waveguides are first diced perpendicular to the waveguide. Referring to Figure 9, the layered structure discussed with reference to Figures 3 and 4 is again etched back to expose the n-type GaN layer 10 and the waveguides. The wafer is then diced perpendicular to the direction of the waveguides as indicated by the arrow labeled D. This operation cuts the waveguides into approximately the correct lengths and exposes the AlN layer 9. The surfaces generated by the dicing operation are not of the quality needed for the end mirrors of the LD. However, the dicing operation exposes the AlN layer 9. The exposed AlN layer is then selectively etched to create the gap 14 under the GaN layers as shown in Figure 10. The cantilevered portion of the GaN layers over gap 14 may now be cleaved by applying a blade in the direction indicated by the arrows labeled "E" in Figure 11. The cleaved surface 15 provides the mirrored ends of the laser cavity. The individual LDs may now be separated from one another by dicing parallel to the laser cavity as shown in Figure 12.

Various modifications to the present invention will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Accordingly, the present invention is to be limited solely by the scope of the following claims.

WHAT IS CLAIMED IS:

1. A method for fabricating a semiconductor laser comprising the steps of:

depositing a buffer layer[9] on a substrate[8];

depositing a crystalline layer[10-13] on said buffer layer[9], said crystalline layer[10-13] comprising a waveguide for said semiconductor laser;

etching a protion[110] of said buffer layer[9] from under said crystalline layer[10-13] leaving a protion[110] of said crystalline layer[10-13] cantilevered over said substrate[8]; and

cleaving said crystalline layer[10-13] in said cantilevered protion[110] to generate a reflecting surface[15] for reflecting light generated in said waveguide.

2. The method of Claim 1 wherein said substrate[8] comprises sapphire;

3. The method of Claim 1 wherein said buffer layer[9] comprises AlN.

4. The method of Claim 1 wherein said crystalline layer[10-13] comprises GaN.

5. A semiconductor laser comprising:

a substrate[8];

a buffer layer[9] deposited on said substrate[8]; and

a waveguide comprising a crystalline layer[10-13] deposited on said buffer layer[9], a protion[110] of said waveguide being cantilevered over said substrate[8], said buffer layer[9] not being in contact with said cantilevered protion[110],

wherein said waveguide comprises a cleaved facet for reflecting light generated in said waveguide, said cleaved facet being located in said cantilevered protion[110] of said waveguide.

6. The semiconductor laser of Claim 5 wherein said substrate[8] comprises sapphire;

7. The semiconductor laser of Claim 5 wherein said buffer layer[9] comprises AlN.

8. The semiconductor laser of Claim 5 wherein said crystalline layer[10-13] comprises GaN.

FIGURE 1

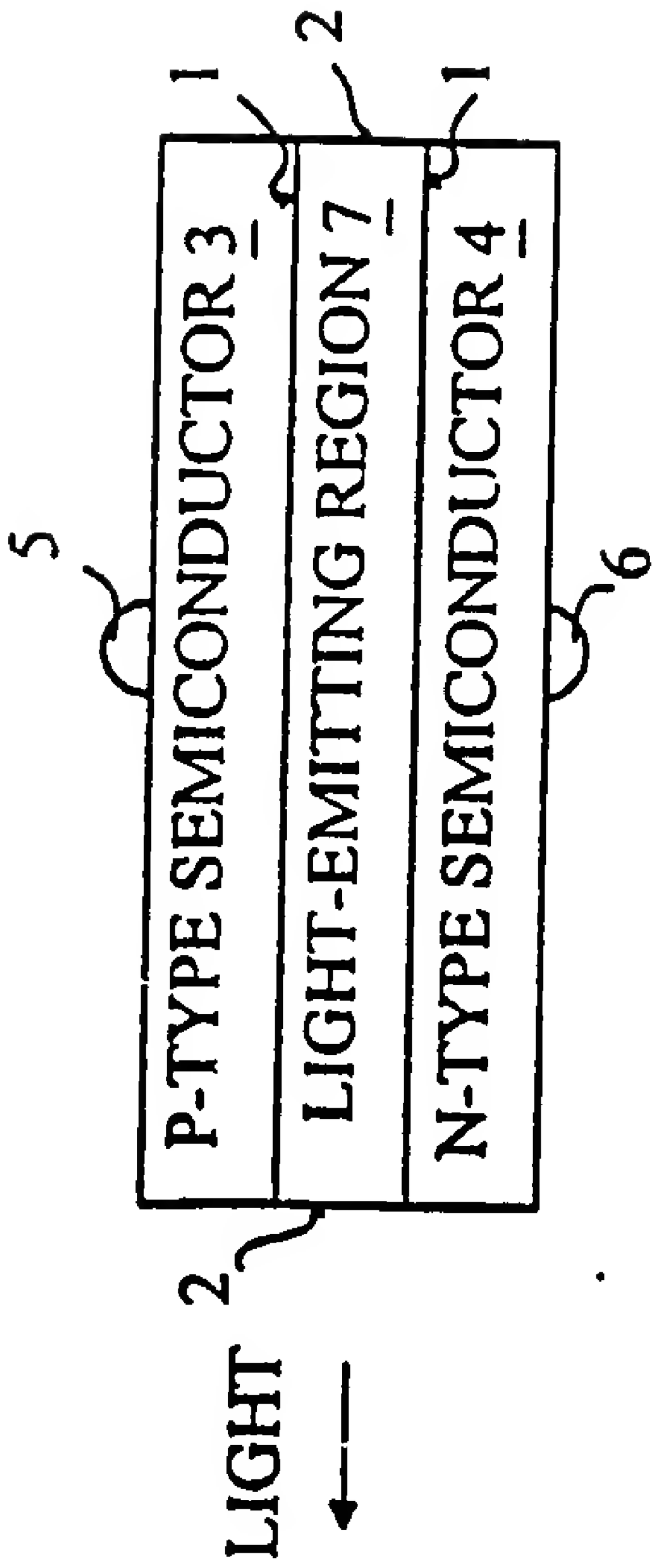
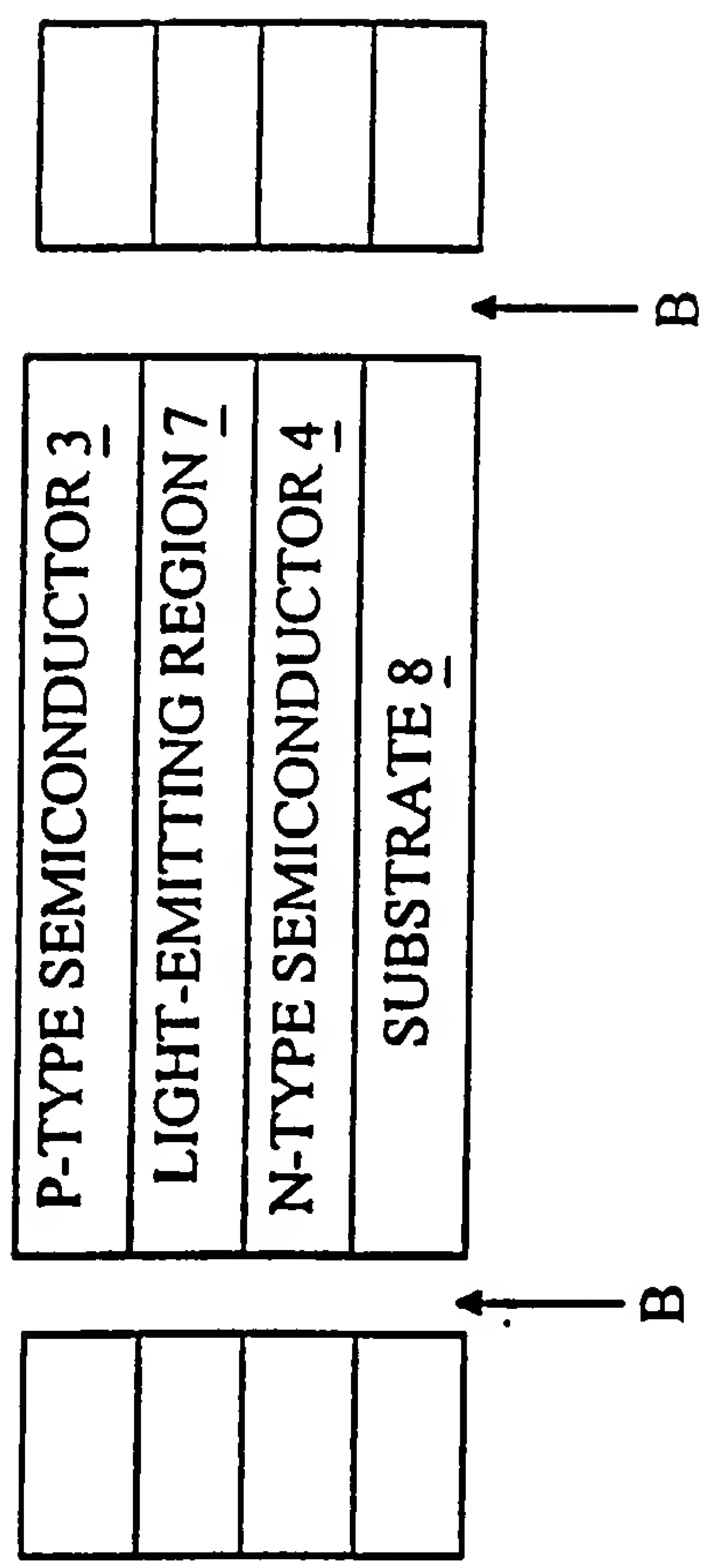

P-TYPE SEMICONDUCTOR 3
LIGHT-EMITTING REGION 7
N-TYPE SEMICONDUCTOR 4
1
2
1
5
6
2
LIGHT

FIGURE 2


B
P-TYPE SEMICONDUCTOR 3
LIGHT-EMITTING REGION 7
N-TYPE SEMICONDUCTOR 4
SUBSTRATE 8
B

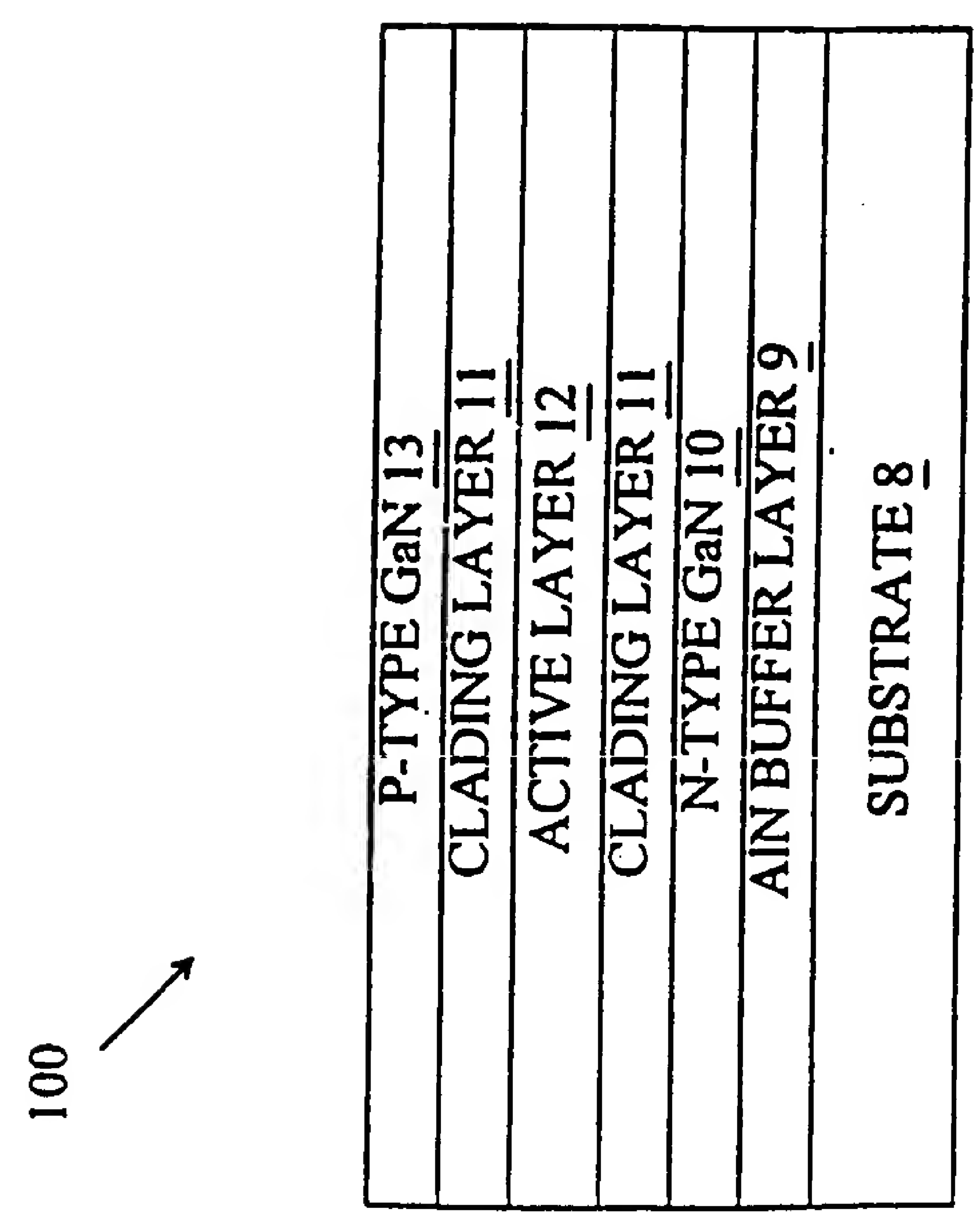


FIGURE 3

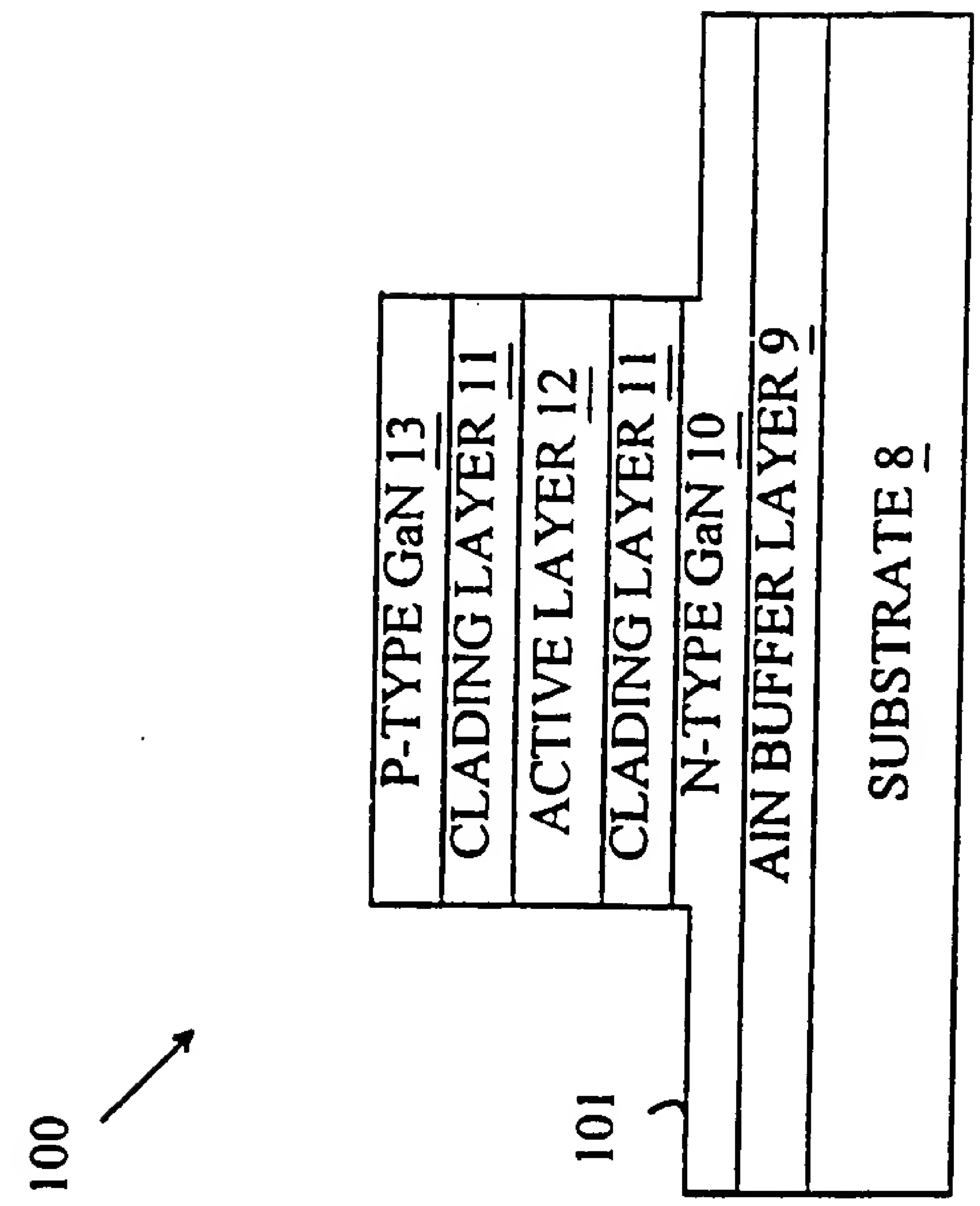


FIGURE 4

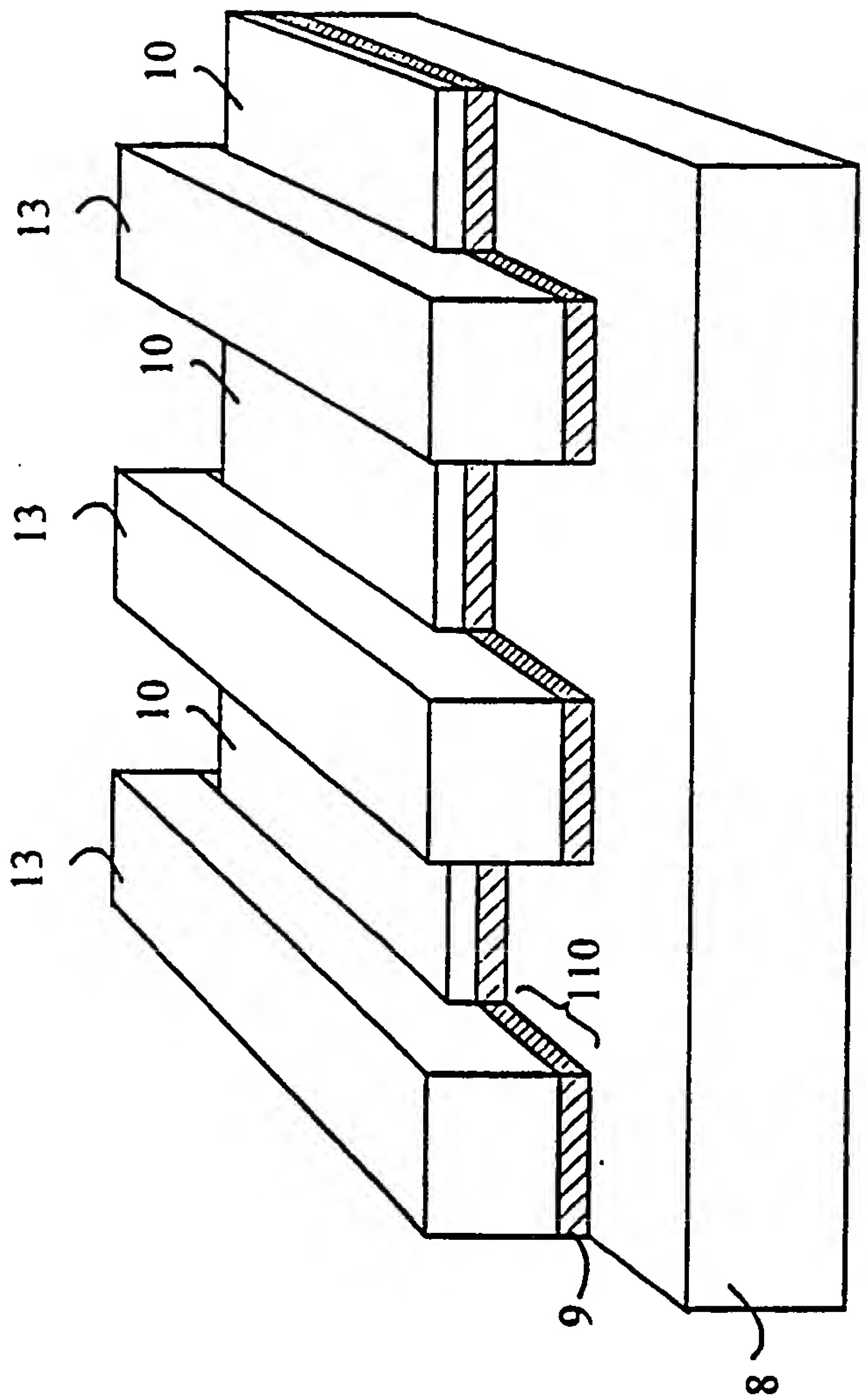


FIGURE 5

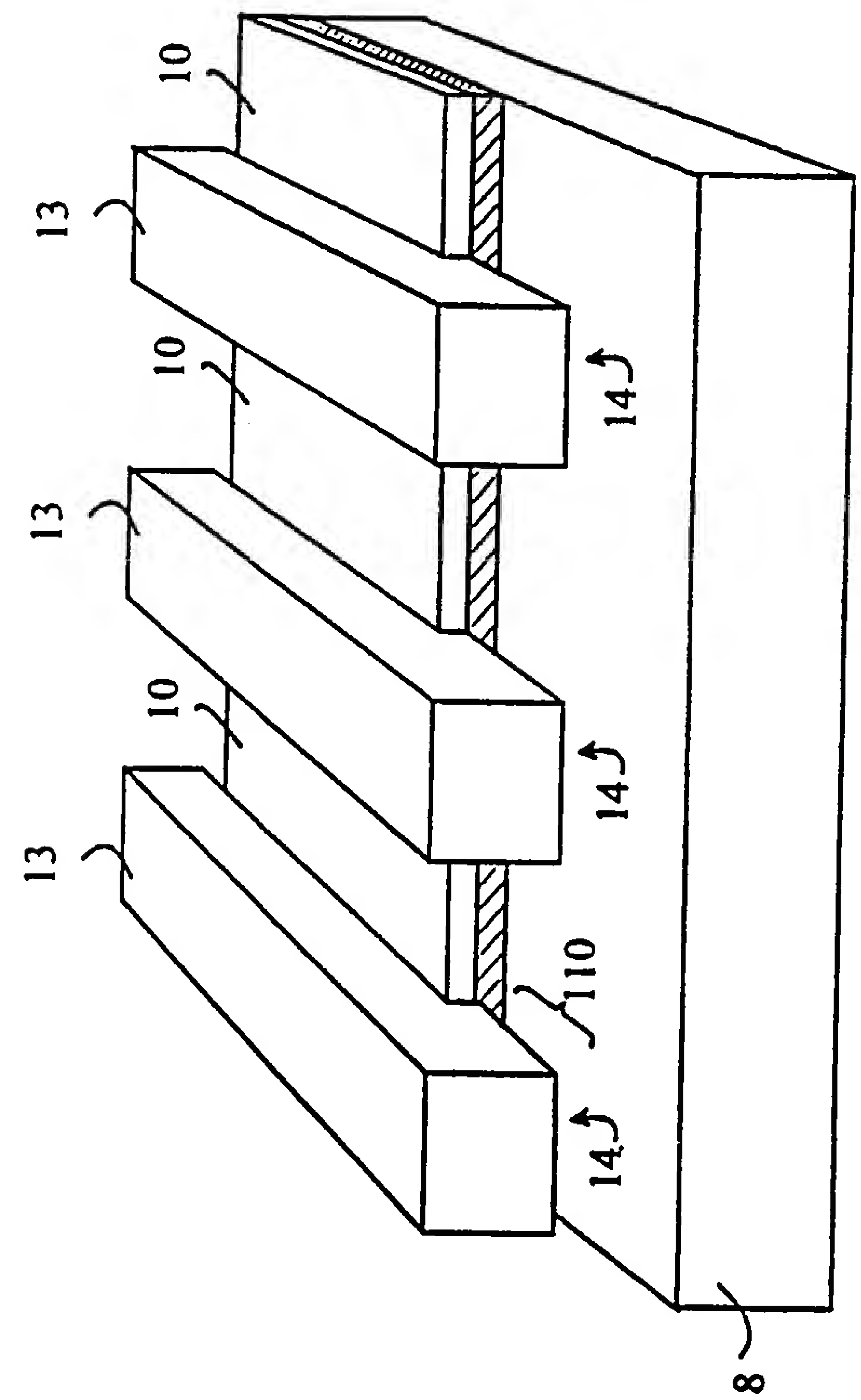


FIGURE 6

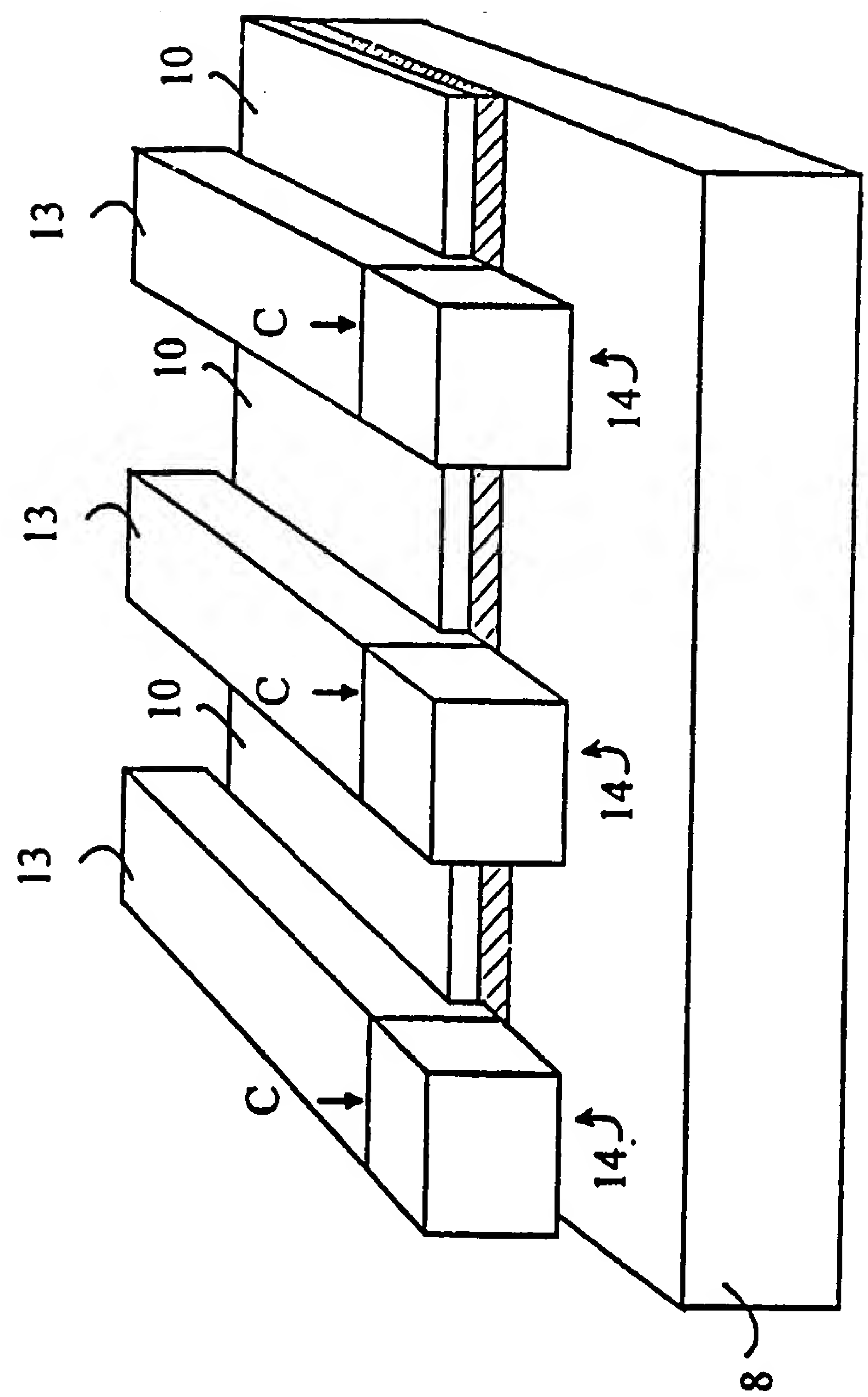


FIGURE 7

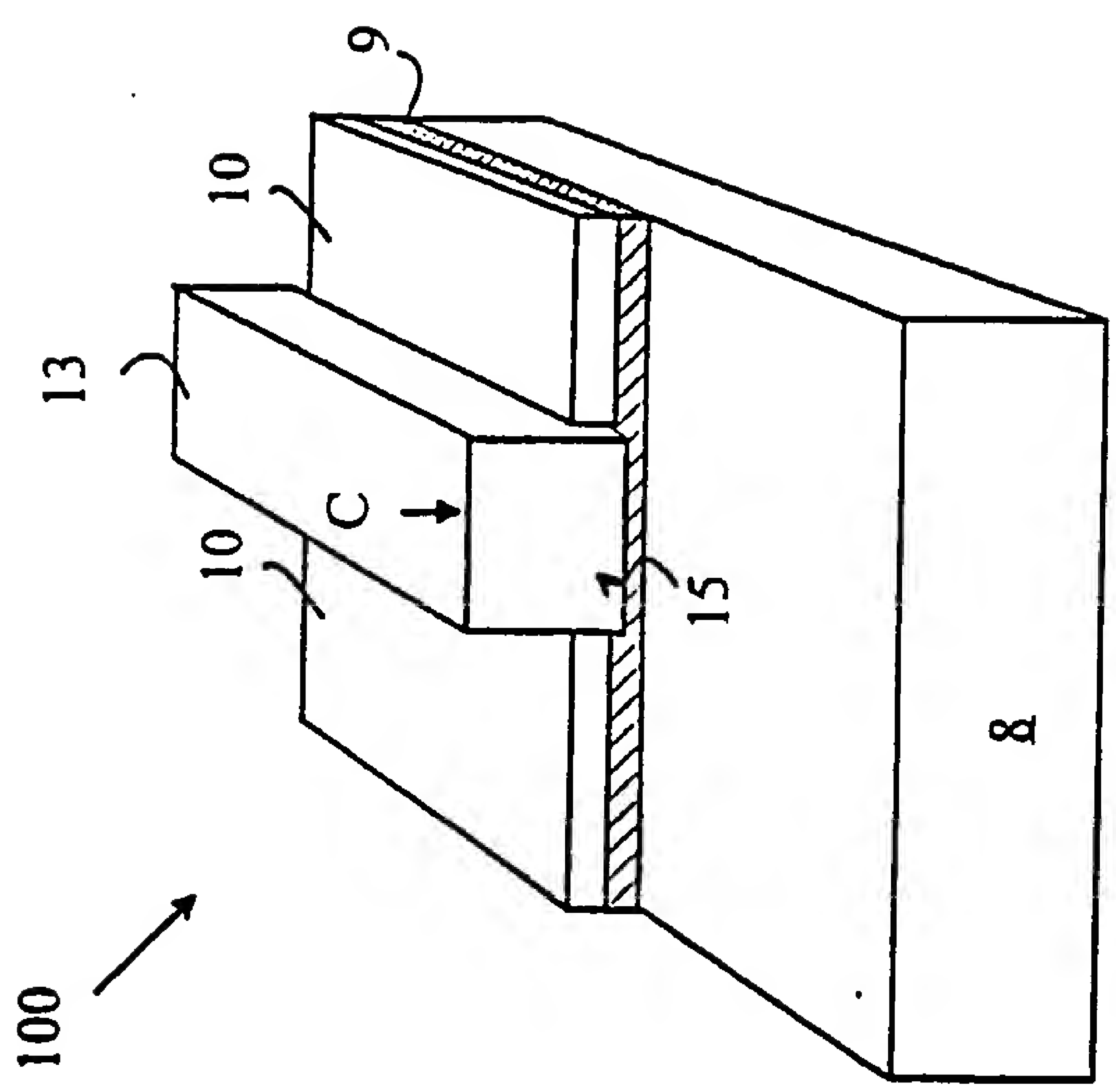


FIGURE 8

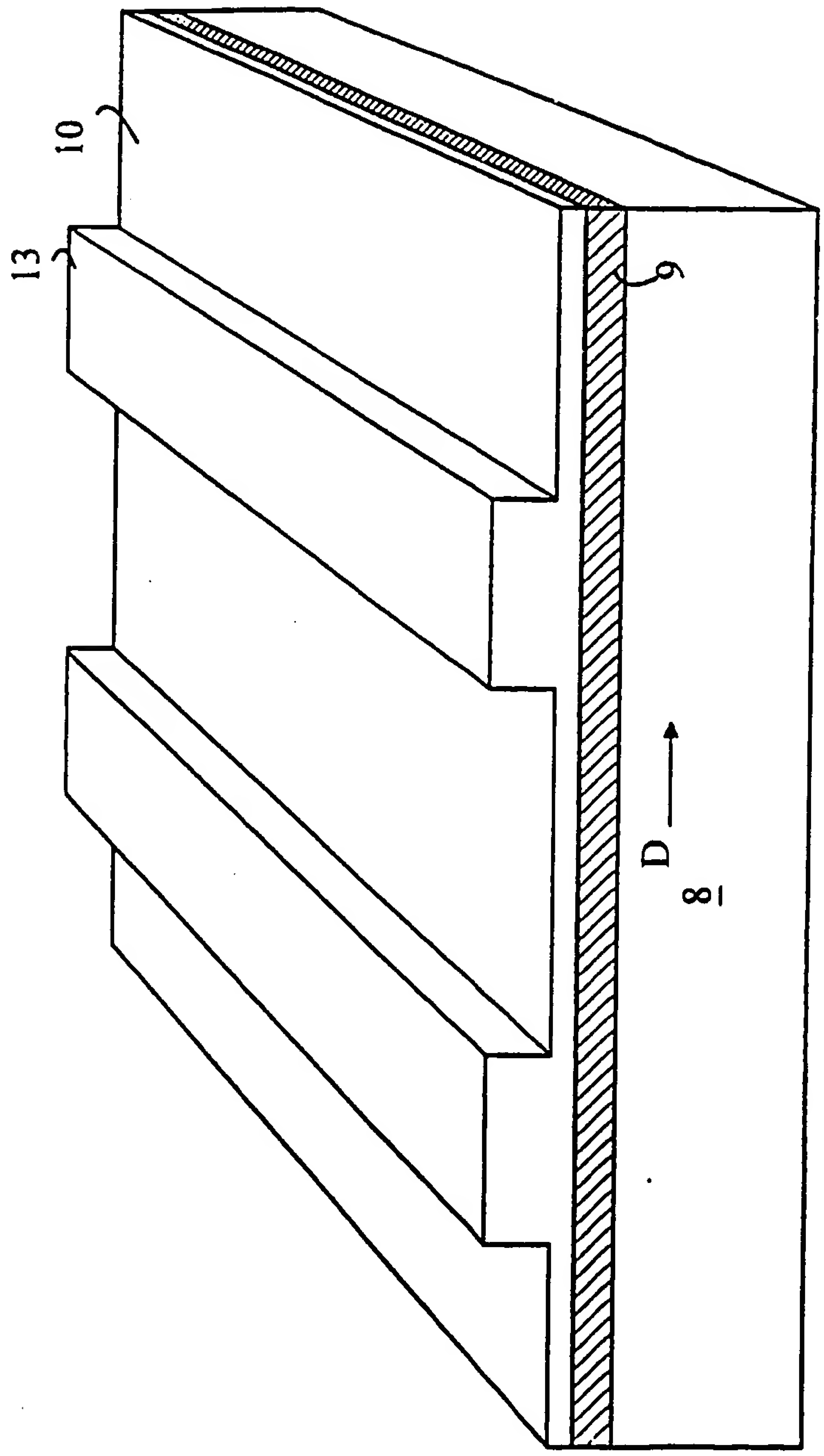


FIGURE 9

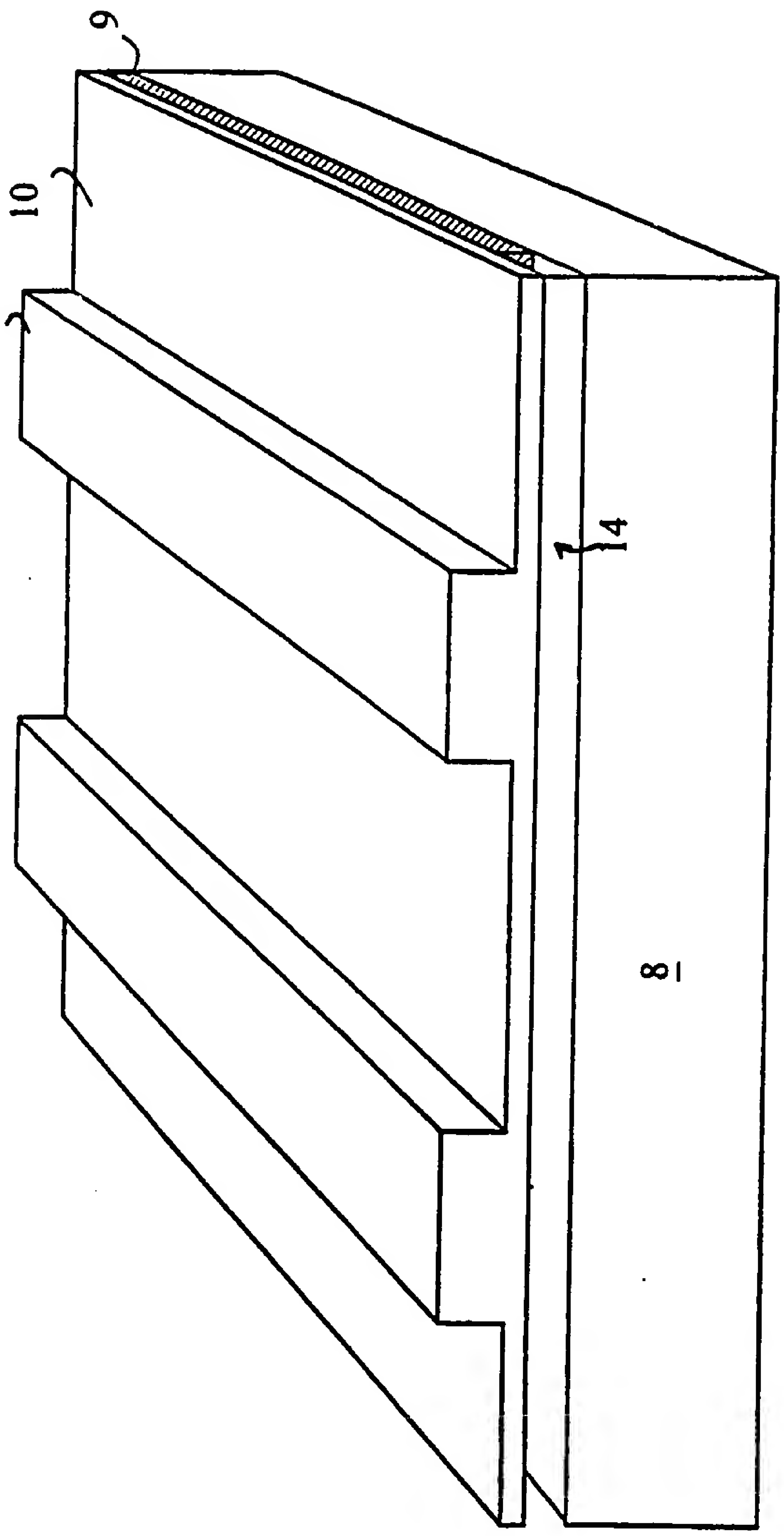


FIGURE 10

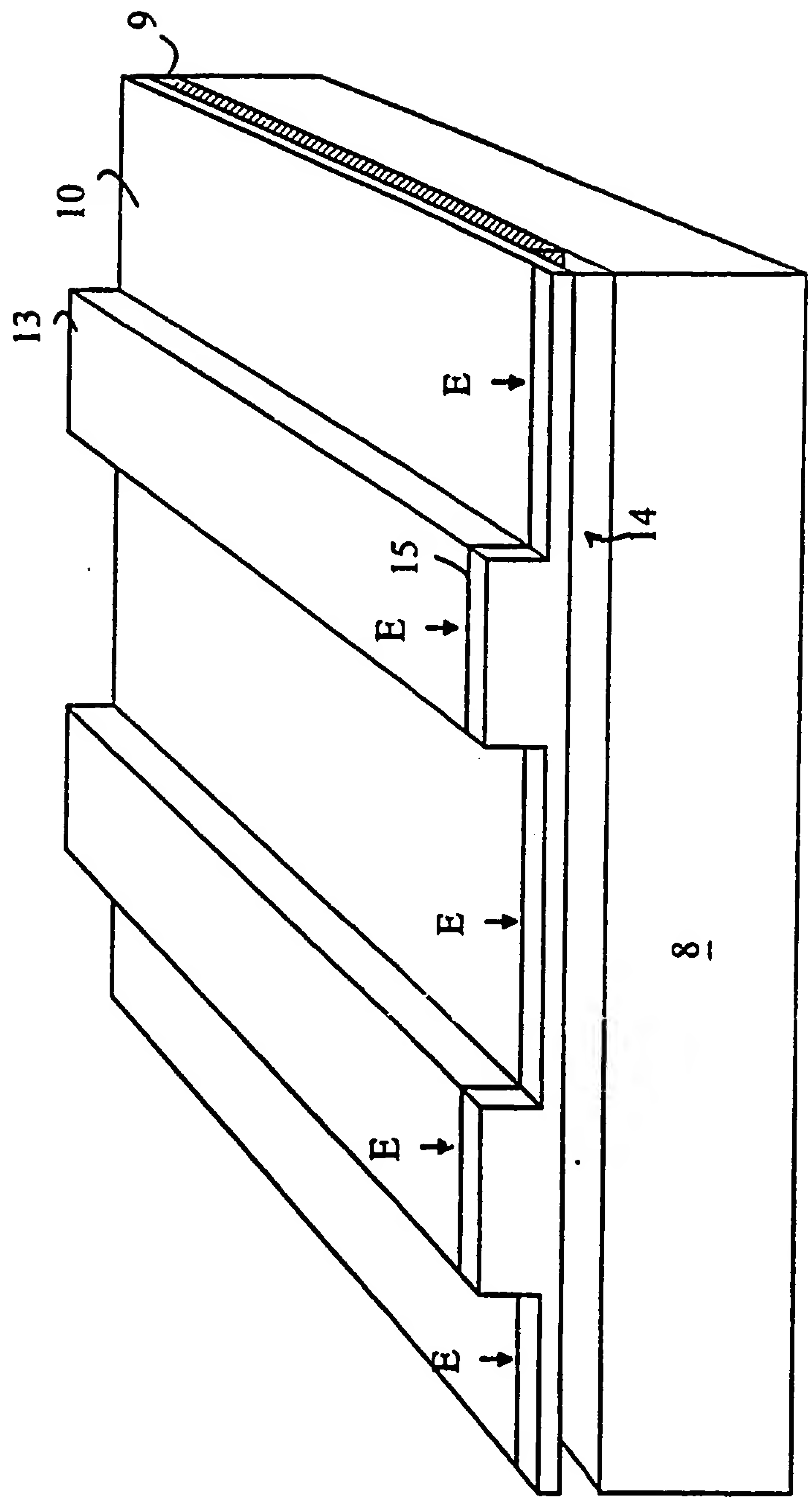


FIGURE 11

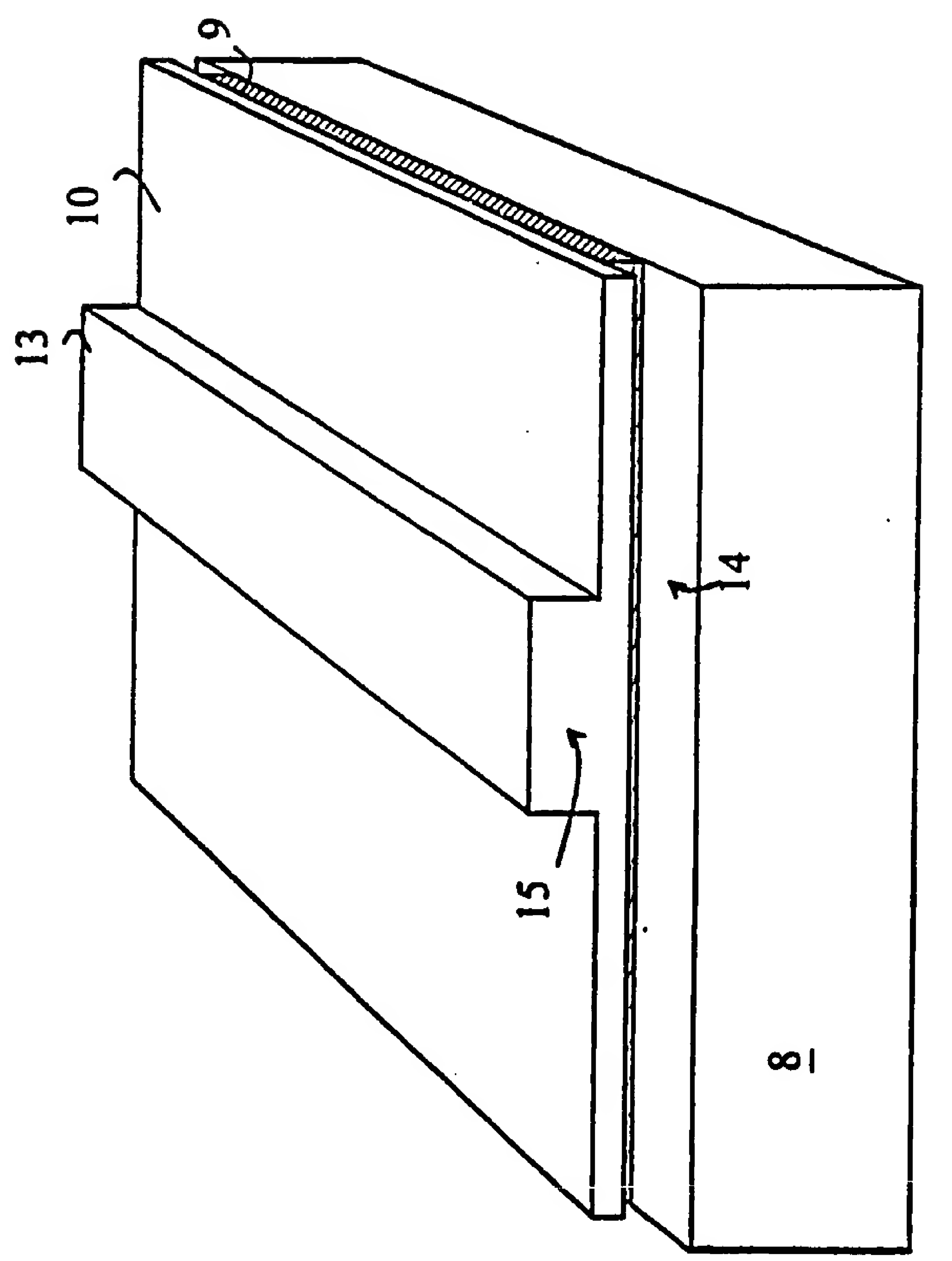


FIGURE 12

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/01494

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01S3/025 H01L33/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WADA O ET AL: "AN ALGAAS/GAAS SHORT-CAVITY LASER AND ITS MONOLITHIC INTEGRATION USING MICROCLEAVED FACETS (MCF) PROCESS" IEEE JOURNAL OF QUANTUM ELECTRONICS, vol. QE-20, no. 2, February 1984, pages 126-130, XP000705606 see chapter "II. FABRICATION METHOD" see figures 1,2 ---	1,5
X	BLAUVELT H ET AL: "AIGAAS LASERS WITH MICRO-CLEAVED MIRRORS SUITABLE FOR MONOLITHIC INTEGRATION" APPLIED PHYSICS LETTERS, vol. 40, no. 4, 15 February 1982, page 289/290 XP000706191 see the whole document ---	1
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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1

Date of the actual completion of the international search	Date of mailing of the international search report
7 May 1998	20/05/1998

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 758 532 A (YAGI TETSUYA ET AL) 19 July 1988 see column 5, line 51 - column 6, line 11; figures 4A,-,4E	1
X	PATENT ABSTRACTS OF JAPAN vol. 010, no. 356 (E-459), 29 November 1986 & JP 61 154193 A (NEC CORP), 12 July 1986, see abstract	1
X	PATENT ABSTRACTS OF JAPAN vol. 010, no. 248 (E-431), 26 August 1986 & JP 61 077385 A (FUJITSU LTD), 19 April 1986, see abstract	5
Y	EP 0 573 724 A (IBM) 15 December 1993 see column 2, line 45 - column 6, line 55; figures 1E,-,1H	1-8
Y	EP 0 688 070 A (TOYODA GOSEI KK ;JAPAN RES DEV CORP (JP); AKASAKI ISAMU (JP); AMAN) 20 December 1995 see page 1, line 19 - page 1, line 27 see page 4, line 46 - page 5, line 43; figure 1	1-8

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 98/01494

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4758532 A	19-07-88	JP 2017200 C	19-02-96
		JP 7016077 B	22-02-95
		JP 62086786 A	21-04-87
		US 4769342 A	06-09-88
EP 0573724 A	15-12-93	DE 69204828 D	19-10-95
		DE 69204828 T	02-05-96
		JP 6037404 A	10-02-94
		US 5284792 A	08-02-94
EP 0688070 A	20-12-95	JP 7297495 A	10-11-95
		JP 7297496 A	10-11-95
		US 5604763 A	18-02-97